A Lifecycle Architecture for Road Infrastructure Finance

Mature-Network Charges, New-Capacity Tolls, Regulated Traffic Allocation and Asymmetric Concessions

Abstract

Road-financing policy is frequently presented as a choice between tax-financed free access and permanent payment per use. This paper argues that this binary framing confuses distinct economic functions. Financing an already constructed and substantially amortised network, recovering investment in genuinely new capacity, and pricing congestion are different problems and need not be addressed by the same instrument. The paper proposes a lifecycle architecture in which mature high-capacity networks are financed primarily through broad network-access charges, while new capacity may be financed through project-specific toll concessions. The model separates non-contestable or administratively determined costs such as compulsory land acquisition from contestable construction costs that the concessionaire can genuinely manage. It also sets out an explicit procurement sequence from land and regulatory-cost preparation, through concession award and detailed technical design, to a separate auction of the economic right to future dynamic congestion-surcharge revenues. The latter is an optional capacity-adequacy mechanism: dynamic scarcity revenues are not retained by the road concessionaire, and a calibrated share of their auction value may instead be charged to the concessionaire, creating an incentive to design adequate capacity before construction. A one-time design re-optimisation option can allow the concessionaire to revise lane configuration at a non-refundable cost and trigger a new congestion-right auction. The paper further develops an asymmetric concession with an ordinary duration, a high upper-return threshold, a low non-guaranteed recovery reference and an absolute maximum duration. Individual components have international precedents; the potential contribution is their integration into a coherent lifecycle and incentive architecture. The final sections illustrate the model through the AP-7 corridor in Catalonia.

Keywords: road pricing; motorway concessions; natural monopoly; vignette; traffic allocation; toll roads; flexible-term concessions; internal rate of return; infrastructure finance; public-private partnerships; AP-7; congestion; dynamic congestion pricing; congestion-rent auction; capacity incentives

JEL codes: H54, H44, L92, R42, R48

Notation and abbreviations

The paper uses the following notation. Abbreviations are also expanded at their first substantive use.

Symbol / acronym	Meaning	Role in the paper
PPP	public-private partnership	Contractual structure combining public authority and private participation.
LPVR	Least Present Value of Revenue	Flexible concession mechanism in which the franchise ends after the contracted present value of revenue is reached.
IRR	internal rate of return; in the upper-return test, cumulative unlevered pre-tax project IRR	Annualised inception-to-date project return, recalculated periodically and used for the upper-return termination trigger; financing structure and corporate income tax are excluded.
CAPEX	capital expenditure	Investment expenditure, especially construction and major capital works.
OPEX	operating expenditure	Recurring operating and maintenance expenditure.
NCF	net cash flow	Eligible net cash flow applied to the recovery balance.
PVR	present value of revenue	Discounted value of a stream of concession revenues.
SMC	social marginal cost	Private marginal cost plus the external cost imposed on other users.
E	existing / mature network	Infrastructure that has moved beyond its original project-financing phase.
N	new capacity	Genuinely new infrastructure or capacity requiring fresh investment.
V	network-access charge	Vignette or equivalent broad access charge for the mature network.
Q, K	traffic volume; capacity	Variables used in congestion and capacity conditions.
α	regulated traffic share	Share of a defined traffic category allocated to the new facility.
T_0; T_max	ordinary; absolute maximum concession duration	Temporal limits of the asymmetric concession.
r_U; r_R	upper return threshold; reference recovery rate	High early-termination threshold and low non-guaranteed recovery reference.
B_t	regulated recovery balance	Eligible investment plus reference accrual less eligible recovery cash flows.
τ_c	congestion charge	Dynamic or variable charge used to manage scarce road capacity.
A	auction value of congestion-revenue right	Upfront price offered for the economic right to eligible future congestion-surcharge revenue.
λ	capacity-adequacy contribution coefficient	Share or multiplier linking the concessionaire contribution to the auction value A.

Symbol / acronym	Meaning	Role in the paper
ρ	design re-optimisation fee coefficient	Fraction used to calculate the non-refundable cost of reopening the technical design after the first congestion-right auction.
JEL	Journal of Economic Literature classification	Standard subject classification used in economics papers.
C_R, C_P, C_S	regulated/non-contestable; private contestable; shared/contingent costs	Cost-allocation blocks used in procurement design.
P, S	concession premium; public subsidy	Alternative bid variables depending on whether the franchise has positive or negative private value.
V_C	private value of concession franchise	Sign determines whether the tender can maximise a premium or minimise a subsidy.
p^B, p^C	base toll; dynamic congestion surcharge	Separates predictable concession revenue from scarcity pricing.
e_i	traffic eligibility indicator	Determines whether user class i is exposed to the dynamic surcharge.
A*	benchmark congestion-right value	Optional threshold below which no capacity-adequacy contribution is charged.
D	non-refundable design reopening charge	Cost of exercising the pre-construction design re-optimisation option.
U,PT	unlevered, pre-tax	Superscript identifying the cash-flow and IRR measure used for the dynamic upper-return test.

Structure of the paper

The paper proceeds from economic decomposition and natural-monopoly theory to traffic allocation, flexible concessions, legal safeguards, and a practical application to the AP-7 corridor.

1. Introduction

A motorway can be expensive to build, relatively inexpensive to accommodate one additional vehicle when uncongested, expensive to maintain over its life, and extremely costly at the margin once congestion appears. Those facts describe different economic problems.

Public debate nevertheless tends to reduce road financing to a binary question: should motorists pay tolls or should roads be free? A more useful starting point is to separate four functions: original capital recovery, maintenance and renewal, new-capacity finance, and congestion or externality pricing.

An amortised motorway does not become costless. Pavement, bridges, drainage, signalling, policing and traffic management continue to require expenditure. But the persistence of maintenance costs does not imply that the original capital-recovery toll must be recreated indefinitely. Likewise, an amortised but congested motorway may rationally be priced, although the justification would then be marginal congestion cost rather than a second recovery of historic construction expenditure.

The proposed architecture treats road infrastructure as an asset that moves through economic stages rather than as a permanently 'free' or 'tolled' road.

$$\text{new infrastructure} \rightarrow \text{project financing} \rightarrow \text{amortisation} \rightarrow \text{mature network}$$

2. The economic decomposition of a road

Let the lifecycle cost of road infrastructure be decomposed into initial investment, ordinary maintenance, operation, major renewal and external costs. Amortisation primarily affects the first component.

This yields an important distinction between capital-recovery pricing and network-maintenance pricing. Users may coherently continue contributing after initial capital has been amortised without perpetuating the original concession tariff.

Norway provides a useful institutional intuition: toll collection attached to a specific project normally ends when the relevant loans have been repaid or the authorised tolling period expires. The road still requires expenditure afterwards, but the financing instrument attached to the original project has an endpoint.

$$C = I + M + O + R + X$$

3. Layer I: the mature network

Once a road has moved beyond its original capital-recovery phase, it can be treated as part of a mature high-capacity network. Rather than pricing every journey separately, access may be financed through a broad network charge.

For light vehicles, one possible instrument is a time-based vignette. Switzerland offers the simplest well-known example; Austria combines a general vignette with separately tolled exceptional sections. The conceptual point is that users purchase access to the network, not passage through a particular historic financing project.

For recurrent users, the average network-access cost per journey falls with use. For occasional users, a rational system should include short-duration products. EU law already reflects this concern in its treatment of time-based charges and non-discrimination.

$$AC_V(q) = V / q$$

4. Layer II: genuinely new capacity

Suppose an existing corridor is chronically congested and additional capacity creates positive net social value. The additional facility involves fresh capital expenditure and can therefore support a project-specific financing toll.

There is no contradiction between opposing a renewed capital-recovery toll on an already amortised motorway and accepting a toll on genuinely new capacity. The two assets are at different points in their economic lifecycle.

Once the new facility completes its financing stage, its institutional status should change: it ceases to be a project-financing asset and enters the mature network.

$$E \rightarrow \text{network-access regime}$$

$$N \rightarrow \text{project-toll regime}$$

$$\text{once financing ends: } N \rightarrow E$$

5. Cost architecture: regulated, contestable and contingent expenditure

The concession should distinguish costs according to controllability rather than merely according to whether they are fixed or variable. A land-acquisition bill can change materially during expropriation even though the concessionaire has little or no control over that change. Conversely, materials, excavation methods, construction logistics and structural solutions are areas in which private efficiency can matter substantially.

A useful decomposition is between regulated or non-contestable costs C_R, private contestable costs C_P, and shared or contingent costs C_S. The World Bank's PPP risk-allocation guidance follows the same general principle: a risk should be allocated to the party best able to control its probability, its impact, or its cost of absorption. Land acquisition is often retained by the public sector, whereas ordinary construction cost and completion risk are commonly placed on the private party.

C_R can include compulsory land acquisition, legally determined compensation, administrative relocation obligations and other items whose amount is primarily determined by public law or an authority-defined alignment. These costs need not be literally certain. They are better described as administratively determined or non-contestable. Where the public authority acquires the land before tender, the corridor can be delivered to the concessionaire free of land-acquisition risk. Alternatively, the concessionaire may advance certified expropriation payments as a pass-through item without an industrial profit margin.

C_P should include the costs that the concessionaire and its construction contractor can genuinely optimise: earthworks, materials, labour, structural systems, tunnelling methods, logistics, sequencing, procurement and construction management. Those costs are an appropriate field for competitive profit and loss. If an efficient contractor can build the same compliant asset for less, the saving should normally belong to the private side, subject to the return and quality constraints elsewhere in this paper.

C_S contains genuinely mixed risks: exceptional geology, unknown utilities, contamination, archaeological findings, or authority-imposed changes. These items require explicit contractual allocation. If a design change voluntarily proposed by the concessionaire increases the land footprint or creates additional expropriation, the incremental cost can reasonably move from C_R to C_P because it then results from a private design choice.

$$C = C_R + C_P + C_S$$

$$C_R = \text{land} + \text{expropriation} + \text{authority-determined obligations}$$

$$C_P = \text{earthworks} + \text{materials} + \text{structures} + \text{labour} + \text{construction management}$$

6. Procurement and implementation sequence

The institutional sequence matters because the later congestion-capacity mechanism should evaluate a technical design that is already concrete and public. A stylised procedure is as follows.

Stage	Procedure	Economic purpose
1	Public corridor and land preparation	Define corridor, public objectives, compulsory acquisition plan and regulatory-cost envelope. Where feasible, acquire or secure the land before the concession tender.
2	Base concession tender	Tender the right to build and operate under the published base-toll, traffic-allocation and performance rules. If the franchise has positive private value, competition may maximise the premium P paid to the State; if it has negative value, competition may minimise the subsidy S requested.
3	Detailed execution design	The winning concessionaire develops the detailed technical execution plan: number of lanes by section, junction geometry, shoulders, structures, safety systems, construction method and other design choices within the public performance envelope.
4	Technical approval and publication	The authority validates compliance, publishes the capacity model and freezes the design for the next stage. Mandatory or protected traffic categories and their predictable base tariff are identified.

Stage	Procedure	Economic purpose
5	Conditional congestion-right auction	A separate auction reveals the market value A of the economic right to eligible future dynamic congestion-surcharge revenue under the published design. The auction is conditional until the concessionaire either accepts the capacity contribution or exercises the redesign option.
6	Capacity-adequacy choice	The road concessionaire either accepts the design and the corresponding capacity-adequacy contribution λA, or pays the non-refundable redesign fee and reopens the technical plan.
7	Possible design re-optimisation	If the design is reopened, the concessionaire bears the redesign and additional construction costs, the authority re-approves and republishes the plan, and the congestion right is auctioned again.
8	Final settlement and construction	After the design is frozen, the congestion-right buyer pays A to the State, the concessionaire pays the calibrated capacity contribution, financial close occurs and construction proceeds.
9	Operation	The concessionaire collects the ordinary base toll. The independently determined congestion surcharge is collected under the public algorithm but economically belongs to the separately auctioned congestion-revenue right. Performance is monitored continuously.

This order prevents the congestion-right auction from becoming an abstract forecast detached from engineering. It values the expected scarcity of a specific, published design. It also prevents the concessionaire from changing lane numbers after learning the value of congestion without bearing a cost for reopening the design.

$$\text{If } V_C > 0\text{: award may maximise P; if } V_C < 0\text{: award may minimise S}$$

7. Natural monopoly at corridor level

Road corridors often possess large sunk costs, spatial indivisibilities, land constraints and economies of density. The relevant natural monopoly may therefore exist at network or corridor level rather than at the level of a single carriageway.

In such settings, requiring multiple fully duplicated roads merely to create textbook competition may be wasteful. Competition can instead occur for the right to construct and operate the infrastructure — competition for the market — while the resulting corridor remains a regulated natural monopoly.

This paper therefore accepts the monopoly characteristics of infrastructure but rejects the idea that the resulting franchise should be granted without competitive discipline.

$$C(Q) < C1(Q1) + C2(Q2) + \ldots + Cn(Qn)$$

8. The free-alternative problem

A central financing problem arises when new tolled capacity must coexist with a close toll-free substitute. Users compare their private generalised travel costs, which include time, operating costs and tolls.

If the free route remains sufficiently attractive, the new road may receive too little traffic to recover its investment even when the additional capacity has substantial social value. The Madrid radial motorways are a

strong warning: actual traffic was far below forecasts, and competition from the extensive free road network was one important factor.

The broader lesson is that social value of additional capacity does not automatically imply commercial viability under unrestricted route choice.

$$G_E = t_E(Q_E) + c_E$$

$$G_N = t_N(Q_N) + p_N + c_N$$

$$\text{social value of capacity} \neq \text{voluntary toll-road bankability}$$

9. Traffic is partly endogenous to regulation

Traffic is uncertain, but it is not wholly exogenous. Governments determine vehicle restrictions, freight corridors, environmental zones, speed limits, junction design, hazardous-goods routes, lane reservations and toll structures.

Accordingly, the demand facing a particular facility is partly a function of the regulatory architecture. Where justified, the authority may determine that a proportion of long-distance heavy traffic should use newly created high-capacity infrastructure.

This may colloquially be described as 'forcing traffic', but the more precise economic concept is regulated traffic allocation.

$$Q = f(Y, P, T, \mathcal{R}, \ldots)$$

$$Q_N = Q_N\text{^}v + \alpha Q_H, \quad 0 \leq \alpha \leq 1$$

10. When is traffic allocation legitimate?

Traffic should not be redirected merely because a private concessionaire wants more revenue. The correct sequence is public network objective, traffic rule, and only then the financial consequences.

A defensible rule might require long-distance freight to use a new high-capacity route because this reduces accident exposure, removes heavy traffic from settlements, preserves unsuitable conventional roads and improves corridor reliability.

A weak rule would restrict an old road solely to rescue the concessionaire's revenue forecast. The distinction is between independent public-interest justification and artificial monopoly-rent creation.

A stylised welfare test can therefore include travel-time, safety, environmental, reliability and road-preservation benefits against infrastructure, user-restriction and administrative costs.

$$\Delta W = B_T + B_S + B_E + B_R + B_P - C_I - C_U - C_A$$

$$\text{traffic allocation is justified when } \Delta W > 0 \text{ and the restriction is proportionate}$$

11. Real-world traffic allocation

Spanish law expressly allows heavy vehicles, under certain safety, traffic-flow or environmental restrictions, to be required to continue their itinerary using a toll motorway, with the possibility of toll discounts. This mechanism has been applied in practice.

Heavy vehicles were previously restricted on conventional routes and redirected to the AP-7 and AP-2 while those motorways were still tolled. In the 2018 arrangements, the restriction and resulting displacement of traffic formed an explicit part of the compensatory mechanism.

Current Catalan rules likewise require transit goods vehicles above 7.5 tonnes generally to use motorways and dual carriageways, subject to specified exceptions.

The counterexample is equally important. The Sydney Cross City Tunnel became controversial partly because surface-road changes were perceived as artificially funnelling motorists into a tolled asset. That experience illustrates why the traffic rule must be independently justified, transparent, proportionate and established ex ante.

12. Competition for the natural-monopoly franchise

Once the authority defines the corridor architecture, the right to exploit the resulting natural-monopoly franchise can be awarded competitively. If a publicly announced traffic rule increases expected concession value, competition can capitalise that advantage into the bids.

The resulting regulatory rent need not remain a windfall to the operator. It can be transformed into lower tolls, shorter expected duration, a higher upfront premium paid to the authority, a lower required subsidy or stronger service obligations.

The detailed auction mechanism is deliberately left for a companion paper. The present principle is narrower: regulatory scarcity should be competitively allocated rather than administratively gifted.

13. Traffic-risk uncertainty and the weakness of fixed terms

Even after regulated traffic allocation, substantial uncertainty remains. Freight activity can decline, production locations can change, rail can substitute road freight, operating costs can rise and voluntary traffic can disappoint.

A rigid concession term translates uncertain traffic directly into uncertain total revenue. Forecast errors can then produce either extraordinary profits or insolvency and renegotiation.

This problem motivates flexible-term concessions, which transform part of revenue risk into duration risk.

$$Q_N = Q_R + Q_V$$

$$\text{regulated traffic} \neq \text{guaranteed revenue}$$

14. Existing flexible-term concession theory

Engel, Fischer and Galetovic developed the most influential formulation through Least Present Value of Revenue (LPVR) auctions. Firms bid on the present value of toll revenue they require, and the concession ends once that amount has been collected.

Higher-than-expected traffic shortens the concession; weaker traffic lengthens it. Flexible terms are therefore well established and are not claimed as an innovation here.

Vassallo also highlights a practical criticism: private investors may resist arrangements that truncate upside more strongly than downside. The model developed below deliberately retains a broad zone of ordinary entrepreneurial return while limiting only exceptional outcomes.

$$\Sigma\ [R_t\ /\ (1+r)\^{}t] \geq PVR^*$$

15. Spanish literature and the AP-7 connection

Albalate and Bel analysed fixed versus variable motorway concessions using Spanish data. Their simulations showed that flexible duration could have shortened successful concessions substantially when traffic exceeded expectations, reducing both extraordinary concessionaire profits and user overpayment.

Bel and Fageda also examined the unequal Spanish motorway-financing structure, in which comparable high-capacity infrastructure historically faced tolls in some territories and tax financing in others. This is particularly relevant to Catalonia and the Mediterranean corridor.

The present lifecycle model can be read partly as a response to those two problems: rigid contracts that over-reward unexpected traffic and territorially path-dependent financing regimes.

16. Return caps are not new either

Maximum-return mechanisms also have precedent. The privately developed SR-91 Express Lanes in California operated under a concession with a rate-of-return cap and mechanisms for public capture of excess gains.

The same project also demonstrates the danger of broad non-compete clauses. Restrictions on improvements to parallel general-purpose lanes became controversial and the public authority later bought the franchise.

A return cap alone is therefore insufficient. The contract must also preserve the state's ability to manage the network in the public interest.

17. The proposed asymmetric concession

The proposed concession differs from a pure LPVR contract. It contains four design parameters: an ordinary concession duration T_0, an exceptionally high upper return threshold r_U, a low reference recovery return r_R, and an absolute maximum duration T_max.

The numerical values are illustrative rather than theoretically fixed. A possible example is forty years for the ordinary period, a 15% upper threshold applied to the cumulative unlevered pre-tax project IRR, a 1% or legal/public reference rate for recovery, and an eighty-year absolute maximum. The return test is dynamic: the cumulative project IRR is recomputed throughout the concession and can trigger termination whenever the threshold is reached.

The central idea is not the exact numbers but a two-stage temporal structure combined with asymmetric treatment of extraordinary upside and inadequate recovery.

$$T_0 = \text{ordinary concession duration}$$

$$r_U = \text{upper return threshold}$$

$$r_R = \text{reference recovery return}$$

$$T_max = \text{absolute maximum duration}$$

18. The upper bound: extraordinary success

The upper-return trigger is based on a cumulative, inception-to-date, unlevered and pre-tax project internal rate of return (IRR). It is recalculated periodically throughout the concession rather than only at final maturity. If this realised annualised project return reaches the deliberately high upper threshold at any review date, the project-specific tolling right is automatically terminated under the baseline version of the model, or becomes immediately terminable by the public authority under an optional-call variant.

The upper threshold is not a target, a guaranteed return or a conventional regulated rate of return. Its role is narrower: to prevent a regulated natural monopoly from retaining extreme windfalls because traffic was massively underestimated or market conditions turned unexpectedly favourable. The test may therefore be activated in year 8, 17, 31 or any other review year; there is no need to wait until the ordinary concession period expires.

Between the low recovery benchmark and the high cap lies a wide ordinary commercial range in which the concessionaire retains entrepreneurial upside.

$$IRR_t^{(U,PT)} = IRR(CF_0^{(U,PT)}, \ldots, CF_t^{(U,PT)}); \quad IRR_t^{(U,PT)} \geq r_U \Rightarrow \text{early-termination trigger}$$

19. Measuring the regulated return

The definition of return is critical. The relevant measure is not equity IRR and not a post-tax return. It is a cumulative unlevered pre-tax project IRR, calculated from the inception of the concession to each review date t. Debt proceeds, interest expense, principal repayments, dividends, leverage choices and the corporate-income-tax shield are excluded. This makes the trigger substantially independent of the concessionaire's financing structure and prevents an identical road from producing a different regulated return merely because one bidder uses more debt than another.

For clarity, the paper refers to this measure descriptively as the regulated project IRR. A more literal label would be cumulative unlevered pre-tax project IRR. It is cumulative because every calculation uses cash flows from project inception to date, unlevered because financing flows are excluded, pre-tax because corporate income tax and the debt tax shield are excluded, and dynamic because it is recalculated during the life of the concession.

The regulated cash-flow perimeter must be defined ex ante. Eligible operating expenditure (OPEX), construction and replacement capital expenditure (CAPEX), concession premiums, non-reimbursable private project costs, related-party transactions, refinancing gains and extraordinary distributions require explicit treatment. Corporate income tax and financing-related tax shields are excluded from the pre-tax return measure; unavoidable non-income taxes that constitute genuine project costs may be included only if the contract expressly classifies them as eligible.

The objective is not ad hoc retrospective regulation but a predictable contractual termination condition. The calculation should be made at predefined review dates, normally at least annually, on audited inception-to-date project cash flows. In early years an IRR may be negative, undefined or economically meaningless because cumulative positive cash flow has not yet offset the initial investment; in that case the upper-return trigger is simply inactive until a valid positive project IRR exists.

$$CF_t\text{^}(U,PT) = R_t - OPEX_t\text{^}eligible - CAPEX_t\text{^}eligible - C_t\text{^}other,eligible \quad \text{(excluding debt service, dividends and corporate income tax)}$$

20. The lower benchmark is not a guarantee

On the downside, the model uses a regulated recovery balance. The concessionaire begins with eligible investment I_0 and the outstanding balance evolves by applying the low reference recovery rate and subtracting eligible net cash flow (NCF) from tolling.

The reference rate may be a fixed low real rate, the legal interest rate, a government-bond-related benchmark or another transparent public index.

Its function is not to guarantee investor profitability. It only determines whether the operator may enter or remain in the extraordinary recovery period.

$$B_0 = I_0$$

$$B_t = B_\{t-1\}(1+r_R) - NCF_t$$

$$r_R \neq \text{guaranteed minimum IRR}$$

21. Ordinary and extraordinary duration

At the end of the ordinary period T_0, the recovery balance is tested. If it has already been extinguished, the concession terminates normally.

If a positive balance remains, the concession may continue into a predefined extraordinary recovery period. During that period, tolling ends as soon as the recovery balance is extinguished.

If the absolute maximum duration T_max is reached with a positive balance still outstanding, the concession ends nevertheless and the residual shortfall is borne by the investor.

$$\text{if } B_T_0 \leq 0 \Rightarrow \text{ordinary termination}$$

$$\text{if } B_T_0 > 0 \Rightarrow \text{extraordinary recovery period}$$

$$\text{if } B_t \leq 0 \text{ for } T_0 < t < T_max \Rightarrow \text{termination}$$

$$\text{if } t = T_max \Rightarrow \text{termination regardless of } B_t$$

22. The complete asymmetric rule

The concession is deliberately asymmetric. Exceptional success shortens the franchise; moderate underperformance can lengthen it; extreme underperformance eventually remains a private loss.

This is neither a conventional fixed-term concession nor a public guarantee of return. It is an asymmetric return-duration corridor.

$$\text{exceptional success} \rightarrow \text{shorter concession}$$

$$\text{moderate underperformance} \rightarrow \text{additional recovery time}$$

$$\text{extreme underperformance} \rightarrow \text{private residual loss}$$

23. Duration as a shock absorber

The core intuition is to convert part of revenue risk into duration risk. Under a rigid forty-year concession, strong traffic can create a windfall while weak traffic can create insolvency. Under a variable arrangement, strong traffic can shorten duration and weak traffic can lengthen it.

The contract therefore absorbs moderate forecasting error through time rather than through immediate fiscal intervention or bailout.

$$\text{convert part of revenue risk into duration risk}$$

24. Why retain some upside?

A concessionaire should not be regulated to the low reference recovery rate. If r_R is 1% and r_U is 15%, the contract does not terminate at 5%, 7% or 10%. Those outcomes remain within the ordinary entrepreneurial zone.

This responds to a recognised weakness of some flexible concessions: if all upside is stripped away while downside remains material, private participation becomes unnecessarily expensive or disappears.

The model therefore reserves intervention for the tails rather than micromanaging ordinary profitability.

$$r_R < IRR < r_U \Rightarrow \text{ordinary entrepreneurial outcome}$$

25. Why the lower benchmark should be low

If the state guaranteed full investment recovery plus a low reference rate, the arrangement could resemble government borrowing through a private intermediary. That is not the proposed model.

The state grants additional time, not guaranteed money. Recovery remains uncertain and private capital remains genuinely at risk.

This preserves incentives for realistic forecasts, construction discipline and efficient operation.

$$\text{extension right} \neq \text{payment guarantee}$$

26. Global precedents: the pieces already exist

The architecture deliberately combines instruments that already exist separately. Switzerland illustrates network vignettes; Austria the coexistence of vignette-covered networks and separately tolled sections; Norway finite project-financing tolls; Chile variable-duration concessions; California return caps; Spain regulated diversion of heavy traffic to toll motorways.

Other cases provide warnings rather than templates. The Madrid radials show the danger of optimistic voluntary-demand forecasts, while Sydney illustrates the legitimacy problem created when traffic restrictions appear designed primarily to support concession revenue.

Jurisdiction / model	Relevant element	Relationship to proposal
Switzerland	General motorway vignette	Mature-network access layer
Austria	Vignette plus separately tolled sections	Separates network access from project-specific tolling
Norway	Project tolls normally end after debt/authorised period	Finite financing purpose
Chile / LPVR	Duration adapts to realised toll revenue	Transforms demand risk into duration
SR-91, California	Return cap and excess-profit controls	Upper-return constraint
Spain / AP-7, AP-2	Heavy traffic redirected to tolled motorways	Regulated traffic allocation
Catalonia	Transit freight routed to motorway/dual-carriageway network	Current network-level allocation
Madrid radials	Weak demand despite parallel capacity	Warning on voluntary bankability
Sydney Cross City Tunnel	Controversial traffic funneling	Warning against revenue-driven coercion

27. What is potentially novel?

The paper does not claim novelty for vignettes, project tolls, concession auctions, flexible terms, LPVR, return caps, freight routing or concession extensions individually.

The potential contribution is architectural: mature-network pricing is combined with new-capacity project finance, ex-ante regulated traffic allocation, residual private demand risk, an asymmetric return-duration corridor, and eventual migration of the amortised asset into the mature network.

The institutional regime therefore follows the economic age and financing status of the asset.

$$\text{new capacity} \rightarrow \text{concession financing} \rightarrow \text{amortisation/recovery} \rightarrow \text{mature network}$$

A further optional contribution is the separation of road ownership from congestion-rent ownership. The dynamic scarcity revenue is auctioned independently, its upfront value becomes a market signal of expected capacity scarcity, and the road concessionaire internalises a calibrated portion of that value while retaining the option to re-optimise the design at a real cost before construction. The individual ideas of dynamic highway tolling and congestion pricing are established; the proposed linkage between a separate congestion-revenue auction, a capacity-adequacy contribution and a pre-construction redesign option appears substantially less standard and merits separate empirical testing.

28. Congestion pricing remains a separate instrument

An amortised motorway need not have a zero marginal price. Congestion generates an external cost because each additional vehicle delays other users.

The standard Pigouvian/Vickrey logic therefore supports congestion charging even after construction costs have been recovered. But the justification is scarcity and congestion, not repayment of historic capital.

Functional separation is important: maintenance charges should finance maintenance, project tolls should finance new investment, and congestion charges should price congestion.

$$SMC(q) = t(q) + q \cdot dt(q)/dq$$

$$\tau^* = q \cdot dt(q)/dq$$

29. Dynamic motorway pricing and protected traffic

Dynamic congestion pricing is not limited to urban cordons. Highway managed lanes and express lanes in the United States already vary tolls by time or in response to real-time traffic conditions in order to preserve a target speed or level of service. The Federal Highway Administration treats dynamic pricing as an active demand-management tool and recommends pre-defined performance thresholds and continuous monitoring.

The present model distinguishes an ordinary base toll from an extraordinary congestion surcharge. The concessionaire may retain a predictable base schedule, including normal off-peak and peak prices established in the contract. The dynamic surcharge is activated only when objective traffic conditions approach the performance threshold.

Protected or anchor traffic should be treated separately. If a class of freight is legally required to use the road because the project was designed partly for that traffic, its tariff should remain predictable. It can therefore be limited to the published base or normal peak/off-peak schedule, with no extraordinary congestion surcharge except where the original contract expressly provides otherwise. Discretionary users who have alternatives and are buying speed or reliability are better candidates for the dynamic surcharge.

Neither the road concessionaire nor the eventual owner of congestion-revenue rights should control the pricing algorithm. The public authority or an independent regulator should set the formula and performance objective ex ante, using observable variables such as speed, density, flow and level of service. The right being auctioned is therefore an economic claim on the resulting revenue, not a discretionary power to create congestion charges.

$$p_i(t) = p_i\text{^}B(t) + e_i \cdot p\text{^}C(t)$$

$$e_i = 0 \text{ for protected traffic; } e_i = 1 \text{ for eligible discretionary traffic}$$

$$p\text{^}C(t) = 0 \text{ while the regulated service threshold is satisfied}$$

30. Externalised congestion rent, capacity charge and design re-optimisation

If the road concessionaire receives both the ordinary toll and the extraordinary scarcity rent, a perverse incentive can arise. A narrower road may cost less to build and, if congestion itself increases revenue, the operator may have too little incentive to provide adequate capacity. The optional mechanism proposed here separates ownership of the road from ownership of the extraordinary congestion rent.

After the concessionaire's detailed technical plan has been approved and published, the State auctions a time-limited economic right to the eligible future congestion-surcharge revenue. Let A denote the winning upfront bid. The winner pays A to the State; the State has therefore monetised part of a future congestion tax or charge at present value. The buyer does not operate the road and does not determine the surcharge. It simply receives the revenue generated by the public pricing rule during the contracted period.

The road concessionaire simultaneously bears a capacity-adequacy contribution linked to the revealed value A. In the simplest version it pays λA to the State, where λ is a calibrated fraction or multiplier. The State therefore receives the auction price A from the congestion-right buyer plus the concessionaire's separate capacity contribution. A refined variant may apply the contribution only above a benchmark congestion value A*, or may adjust λ according to how much capacity discretion the concessionaire actually had. The objective is to avoid penalising unavoidable scarcity while still making avoidable under-capacity expensive.

The auction is initially conditional. Before financial close and construction, the concessionaire may exercise a one-time design re-optimisation option if the revealed congestion value makes its proposed capacity economically unattractive. This is a revision of the technical design, not the construction-law concept of physical setting-out. The concessionaire pays a non-refundable reopening charge and bears all redesign and incremental construction costs. The authority then approves and republishes the revised plan and the congestion-right auction is repeated.

Let A_0 be the first auction value. A simple reopening fee can be $D = \rho\lambda A_0$. If, for example, the first capacity contribution would have been 500 million and $\rho = 20\%$, reopening the project would immediately cost 100 million. The concessionaire may nevertheless prefer to incur that cost, add capacity and face a much lower second auction value A_1. The final burden is then the sunk reopening charge plus the capacity contribution associated with the final design.

This mechanism creates a market-based signal before construction. A high A says that independent investors expect valuable future scarcity under the published design. Because the concessionaire internalises a calibrated part of that signal but must also pay the cost of extra lanes, it has an incentive to choose capacity where the marginal cost of expansion is balanced against the expected scarcity cost. The mechanism should not seek zero congestion: some congestion can be economically efficient. Its purpose is to discourage deliberate or negligent under-design and to improve user experience before irreversible construction decisions are made.

To prevent strategic cycling, the number of redesign rounds should be limited and each reopening should have a real non-refundable cost. The congestion-revenue right can also be auctioned in finite tranches rather than for the entire life of the concession, allowing later revaluation as technology and demand evolve.

$$\text{State receipts at final design} = A + \lambda A \quad \text{(baseline form)}$$

$$\text{Capacity-adequacy contribution} = \lambda \cdot \max(0, A - A^*) \quad \text{(benchmark variant)}$$

$$D = \rho\lambda A_0$$

$$\text{Final concessionaire burden after redesign} = D + \lambda A_1$$

$$\text{higher expected scarcity} \rightarrow \text{higher } A \rightarrow \text{stronger incentive to add efficient capacity}$$

31. Avoiding double charging

A coherent architecture should minimise overlapping charges for the same financing function. EU legislation generally restricts simultaneous use of a toll and a time-based user charge on the same vehicle category and road section, subject to specific exceptions.

The lifecycle model fits this logic naturally: a newly built project-tolled facility can remain outside the vignette network while the concession is active and enter the vignette network once the project-specific financing stage ends.

$$\text{while project toll is active: } N \notin V$$

$$\text{after termination: } N \in V$$

32. European legal safeguards

A European implementation must observe non-discrimination, proportionality, genuine operating risk, transparent concession award and the rules governing concession duration and contract modification.

Traffic-allocation provisions and extraordinary duration extensions should therefore be written into the original concession documentation rather than negotiated retrospectively after financial distress.

The theoretical model may examine very long horizons, including eighty or one hundred years, but practical implementation must comply with the legislation in force in the relevant jurisdiction.

$$\text{economic model} \neq \text{current statutory permission}$$

33. No-bailout principle

The model should contain an explicit rule that forecast error alone does not create a right to public compensation.

If demand is weak, time is the first shock absorber. If the additional period is still insufficient and the hard stop is reached, the remaining recovery balance is lost.

This discourages the sequence of optimistic bidding, award, traffic shortfall, renegotiation and public rescue that has troubled numerous public-private partnerships (PPPs).

$$\text{forecast error alone} \neq \text{right to compensation}$$

34. Government-induced regulatory risk

Market risk should be distinguished from unilateral government change. If a concession is tendered on the basis of an explicit traffic-allocation rule and a later government abolishes that rule, the resulting loss is not ordinary demand risk.

A predefined rebalancing or compensation mechanism may therefore be justified for clearly specified government-induced changes, while leaving ordinary market risk private.

$$\text{market risk} \neq \text{unilateral regulatory change}$$

35. No blanket non-compete protection

The state should generally avoid promising that no competing transport infrastructure will be built for decades. Such clauses can block future welfare-improving investments.

Traffic allocation is conceptually different. The concessionaire may rely on the traffic rules explicitly tendered, but should not receive a veto over future infrastructure policy or technological change.

A useful principle is: protect the contractual rule, not the concessionaire from every future development.

36. Application to the AP-7 in Catalonia

The AP-7 is an unusually suitable practical case because its history contains almost every element discussed above. It was one of Spain's principal toll corridors, its long-standing concessions ended in 2021, and traffic increased sharply after toll removal.

Subsequent studies have described important sections as operating near their capacity limits, and congestion has become a recurring policy concern.

The lifecycle framework suggests that the debate need not be reduced to a choice between a completely free AP-7 and simply restoring the old toll.

37. Stage I: treat the existing AP-7 as mature infrastructure

The historic concession has ended. The existing AP-7 can therefore be conceptually classified as mature infrastructure rather than automatically subjected again to a capital-recovery toll.

In the proposed architecture, the existing motorway would form part of a broader network-financing regime. For light vehicles this could be a national or otherwise legally competent vignette; for heavy vehicles a distance-based charge is likely to be more compatible with the direction of European policy.

This approach also reduces the historical territorial asymmetry produced when similar motorways were financed differently merely because of when and where they were built.

$$AP7_E \subset \text{mature network regime}$$

38. Stage II: separate congestion from financing

If parts of the AP-7 remain congested, the policy question should not be how to restore toll revenue. It should be which welfare-improving instrument best addresses the scarcity.

One response is congestion pricing. Another is new physical capacity. The choice should follow cost-benefit analysis rather than fiscal convenience.

$$\text{if } Q > K\text{: evaluate } \tau_c \text{ versus } \Delta K$$

39. Stage III: construct genuinely new capacity where justified

Where the social value of additional capacity exceeds its cost, the new asset could take the form of a parallel motorway segment, segregated express capacity, dedicated freight lanes, a major bypass or another substantial capacity addition.

This new capacity, unlike the historic AP-7, represents fresh capital and may therefore be financed through a specific project toll.

$$AP7_N \rightarrow \text{project-specific concession}$$

40. Stage IV: regulated freight as anchor traffic

The freight character of the AP-7 makes the corridor particularly suitable for the regulated-traffic component. Catalonia already routes transit heavy goods vehicles towards motorways and dual carriageways, and Spanish law has previously permitted compulsory diversion to tolled motorways.

A new-capacity concession could therefore specify before tender that defined categories of long-distance freight must use the new facility, subject to exemptions for local deliveries, origin/destination traffic, emergencies and other objectively justified cases.

The purpose should be safety, traffic flow, environmental protection, pavement preservation and freight reliability — not a promise of concession revenue.

$$Q_AP7_N = Q_V + \alpha Q_H$$

41. Stage V: make compulsory use affordable

If a category of users is legally required to use a tolled facility, pricing deserves particular care. Captive traffic should not become an excuse for monopoly extraction.

The regulated heavy-vehicle category could therefore face a lower toll than voluntary premium traffic, or receive partial credits against other network charges. Spanish precedent already combines compulsory diversion with toll discounts.

$$p_H < p_V$$

For an AP-7 application, the mandatory long-distance freight class could be protected from the extraordinary dynamic congestion surcharge and pay only the published base/peak schedule. Discretionary light vehicles seeking a faster or more reliable premium route could face the dynamic surcharge when the regulated service threshold is threatened. After the detailed lane plan is public, the State could auction the eligible congestion-revenue right separately and use its market value as an optional capacity-adequacy signal before construction.

If the first auction reveals an unexpectedly high scarcity value, the concessionaire could either accept the corresponding calibrated capacity contribution or reopen the design at a non-refundable cost, for example by adding lanes or redesigning bottlenecks, followed by a second auction. This makes the congestion mechanism preventive as well as operational: it can change the road before it is built, not merely ration traffic after congestion appears.

42. Stage VI: apply the asymmetric concession

The new AP-7 capacity could use the asymmetric concession structure described above. The following numbers are purely illustrative: an ordinary forty-year term, a 15% upper IRR threshold, a low reference recovery rate around 1% or another public benchmark, and an absolute maximum of eighty years.

If traffic is exceptionally strong and the upper return threshold is reached early, the project-specific toll can disappear early. If recovery remains incomplete after the ordinary term, the concession can continue. If the recovery balance is still positive at the hard stop, the concession ends and the investor bears the residual loss.

The mechanism therefore provides downside time without guaranteeing downside money.

43. The concession remains risky

Regulated freight improves demand visibility but does not eliminate uncertainty. Freight volumes, macroeconomic conditions, construction cost, financing, maintenance, voluntary traffic and technology remain risky.

The hard stop is essential because it preserves the possibility of loss and prevents the extension mechanism from becoming a de facto sovereign guarantee.

$$P(\text{loss}) > 0$$

44. Stage VII: the motorway eventually ceases to be a 'toll motorway'

Once the project-financing right ends, the new road should migrate into the mature network regime. Its future maintenance is then financed under the general network architecture rather than by perpetuating the original project toll.

This creates a dynamic lifecycle: a new road is temporarily a toll-financed capital asset and later becomes ordinary common infrastructure.

If scarcity returns decades later, society reassesses congestion pricing or additional capacity rather than assuming that yesterday's financing instrument must continue forever.

$$\text{new road} \rightarrow \text{temporary toll asset} \rightarrow \text{mature common infrastructure}$$

45. Why the proposal is not anti-toll

The framework permits network access charges, heavy-vehicle distance charges, project tolls, congestion charges and environmental differentiation. It therefore allows more differentiated pricing, not necessarily less pricing.

What it rejects is functional confusion: a toll justified by new investment should not survive indefinitely merely because toll technology exists; a congestion price should not be misrepresented as repayment of historic capital.

46. Compact representation of the model

The complete architecture can be summarised as a sequence of mature-network finance, congestion management, new-capacity investment, regulated traffic architecture, bounded concession rules and final lifecycle transition.

$$E \to V$$

$$\text{if } Q_E > K_E \Rightarrow \tau_c$$

$$\Delta K > 0 \Rightarrow N$$

$$N \to p_N Q_N$$

$$Q_N = Q_V + \alpha Q_R$$

$$IRR \geq r_U \Rightarrow \text{early exit}$$

$$t = T_0 \text{ and } B_t > 0 \Rightarrow \text{extension}$$

$$B_t \leq 0 \text{ after } T_0 \Rightarrow \text{exit}$$

$$t = T_max \Rightarrow \text{absolute exit}$$

$$N \to E$$

47. Relationship with concession-auction design

This paper deliberately stops short of specifying the optimal auction. Once the infrastructure, toll formula, traffic-allocation regime and asymmetric duration rules are fixed, a separate question arises: how should the state award the right to exploit this regulated natural monopoly?

One possible family of tenders would allow the market to reveal whether the franchise has positive or negative private value. If the right has positive value, firms could compete by offering the highest premium to the public authority while assuming the construction cost. If no private actor finds the project viable, competition could instead minimise the subsidy requested.

Winner's-curse effects, strategic forecasts, bid guarantees, renegotiation incentives and the treatment of concession premiums deserve separate analysis in a companion paper.

$$\text{if } V_C > 0\text{: maximise premium } P$$

$$\text{if } V_C < 0\text{: minimise subsidy } S$$

48. Limitations and research agenda

Several issues require further analysis: traffic allocation may change total traffic rather than merely redistribute it; compulsory routing can have heterogeneous welfare effects; rail investment may dominate road expansion; the recovery account must treat inflation, refinancing and replacement capital carefully; an IRR cap can create strategic behaviour near the threshold; and exceptionally long horizons raise governance and intergenerational concerns.

Technological change — electrification, autonomous vehicles, satellite road pricing and freight automation — may also alter the optimal architecture.

Finally, legal implementation varies by jurisdiction. The conceptual framework should therefore be distinguished from the concession form permitted by any one current legal system.

49. Discussion: why the lifecycle perspective matters

Conventional policy language classifies roads by permanent institutional labels: public road, toll road, concession motorway, free motorway. The lifecycle approach instead classifies the financing stage.

A mortgage-financed building does not remain a 'mortgaged building' forever because debt was once necessary to build it. Likewise, infrastructure need not remain a 'toll road' forever merely because toll revenue financed its original construction.

The relevant question is therefore not whether a road has historically been tolled, but what economic function today's charge performs.

$$\text{financing stage} > \text{permanent road type}$$

The procurement sequence adds a further discipline: public or non-contestable land and regulatory costs are separated from privately controllable construction costs; the base concession is awarded; the detailed lane plan is published; and only then is the future congestion-revenue right valued separately. This makes expected scarcity observable before construction and gives the concessionaire a priced opportunity to improve the design rather than profit from avoidable congestion later.

50. Conclusion

This paper proposes treating road infrastructure as an asset that moves through economic stages. New capacity requires capital and can legitimately be financed by a project-specific toll concession. The corridor can be managed as a natural monopoly, and selected traffic can be allocated to new capacity where an independently justified public-interest objective supports the rule.

The concession should retain meaningful private risk. An ordinary duration, a high maximum-return threshold, a low but non-guaranteed recovery reference and an absolute maximum duration can moderate both exceptional upside and moderate downside without guaranteeing recovery.

When the project-financing function ends, the specific toll disappears and the infrastructure becomes part of the mature network. Maintenance charges, heavy-vehicle road-use charges and congestion pricing may remain justified, but they should be tied to present economic functions rather than to the historic fact that the road once required capital.

The individual mechanisms are well precedented. The potential contribution is their integration into a lifecycle architecture that replaces the permanent distinction between toll roads and free roads with a more economically meaningful distinction between new capital, mature capital and scarce capacity.

$$\text{finance new capacity as new capacity}$$

$$\text{manage the corridor as a network}$$

$$\text{cap extraordinary monopoly rents without guaranteeing ordinary returns}$$

$$\text{once capital financing ends, allow the road to become ordinary infrastructure}$$

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